

Detailed studies of crustal and Benioff-Zone earthquakes of the Prince William Sound and southern Kenai peninsula regions, Alaska

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Diane I. Doser

The University of Texas at El Paso

Department of Geological Sciences, 500 W. University Ave., El Paso, TX 79968

(915)-747-5851 (office), (915)-747-5073 (FAX), doser@geo.utep.edu,

http://www.geo.utep.edu/faculty_staff/doser.htm

Element I

Seismology, source characteristics, seismotectonics

Investigations Undertaken:

The proposed research focuses on study of the seismicity (1964-2002) of two regions of the Prince William Sound asperity that ruptured during the 1964 great Alaska earthquake, the Prince William Sound (PWS) and southern Kenai Peninsula regions (SKP) (Figure 1). Study of these regions will provide detailed information on how seismic deformation within the North American and subducting Pacific plate and Yakutat block have changed in time and space since the 1964 mainshock, and will be merged with previous studies of crustal and Benioff-zone seismicity of the Anchorage region (~100 km of Anchorage) that was completed through previous NEHRP support. The two regions contain crucial shipping and transportation facilities that serve much of inland Alaska. The tasks we proposed to accomplish in this study that were judged the most important by the review panel include: 1) detailed relocations of crustal and Benioff-zone earthquakes occurring between 1964 and 2002 in the PWS and SKP regions, 2) examination of the relation of seismicity to known lithospheric structure and observed zones of plate interface locking and relaxation, and 3) integration of results with those obtained for the Anchorage region to obtain a comprehensive view of seismicity within the PWS asperity region since 1964.

Ms. Annette Veilleux has worked as a research assistant on this project. She has organized and reformatted phase data for all events occurring between 1989 and 2002 in the PWS and SKP. Dr. Doser has completed relocations of these events and is currently reformatting phase data for earthquakes occurring between 1971 and 1988 for relocations. Ms. Veilleux will report on preliminary results of merging some of the relocations at the 2005 fall meeting of the American Geophysical Union. Mr. Alejandro de la Peña, has collected digital and analog waveform data for $M > 5.7$ earthquakes occurring between 1980 and 2005 in the Columbia Bay region of PWS and will be analyzing these events as part of his MS thesis.

A paper on the crustal seismicity of the Anchorage region (Flores and Doser, 2005) was published in the Bulletin of the Seismological Society of America, as well as a paper on the historical seismicity of the Kodiak Island (Doser, 2005a). A paper on changes in seismic moment rates within the 1964 rupture zone (Doser et al., 2005) has been submitted to the Bulletin of the Seismological Society of America and a paper on relocating historic (1899-1917) earthquakes of south-central Alaska (Doser, 2005b) has been submitted to Pure and Applied Geophysics. In May 2005 Dr. Doser participated in a workshop sponsored by the USGS in Fairbanks, Alaska to discuss updating seismic hazards maps for the state of Alaska. She also continues to collaborate with Dr. Peter Haeussler, Dr. Natasha Rupert (Ratchkovski), and Dr. Ron Bruhn on research related to the seismicity and tectonics of south-central Alaska.

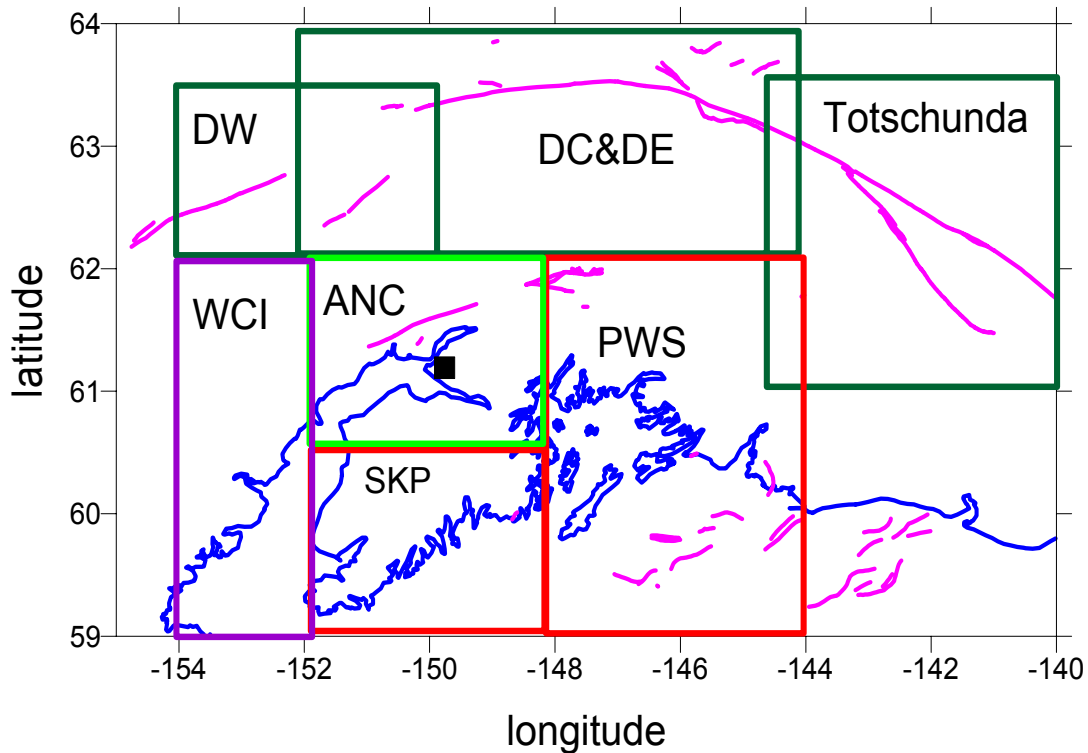


Figure 1 – Map showing location of Prince William Sound (PWS) and southern Kenai Peninsula (SKP) study areas (red boxes). Light green box labeled ANC is the Anchorage study area examined by Flores and Doser (2005) and Veilleux and Doser (2005). Dark green boxes denote regions of the Denali fault studied by Doser (2004). Purple box is the Western Cook Inlet (WCI) region that we plan to merge with the ANC, SKP and PWS regions to obtain a more complete picture of seismicity within the subducting Pacific plate and Yakutat block. Black square is Anchorage. Magenta lines are Holocene and Neogene faults from Plafker et al. (1994).

Results:

Task 1 (Relocation of crustal and Benioff zone earthquakes)

Figures 2 to 7 show relocation of earthquakes occurring between 1989 and 2002 in the PWS and SKP regions obtained using the HypoDD technique. For the SKP region the relocations have been merged with relocations obtained from previous studies of the Anchorage region by Flores and Doser (2005) and Veilleux and Doser (2005).

Figure 2 compares the shallow (< 20 km deep) seismicity of PWS to the Slope Magnetic Anomaly (SMA), marking the edge of the subducted Yakutat block (Griscom and Sauer, 1990) and the 20 km depth contour to the plate interface from Brocher et al. (1994). The solid triangles are seismograph stations and diamonds are $M_w > 5.5$ crustal events occurring since the 1964 mainshock. Orange lines represent Holocene/Neogene faults from Plafker et al. (1994). All earthquakes occurring at depths less than 14 km are occurring within the North American plate, as well as all earthquakes shown to the north of the 20 km depth contour. Note that there are concentrated regions of seismicity at the northern end of Knight Island, along the northwestern margin of PWS and the Copper River Delta. The region of intense activity near 61.5 N, 147 W is the Tazlina Glacier cluster. There is a dramatic decrease in seismicity east of 146 W. These

features have been noted previously by Page et al. (1989) and Ratchkovsky et al. (1998) using less data than we presently have available. Once we relocate events occurring between 1971 and 1988, we plan to examine seismicity variations of these regions in time and space to better delineate earthquake source zones.

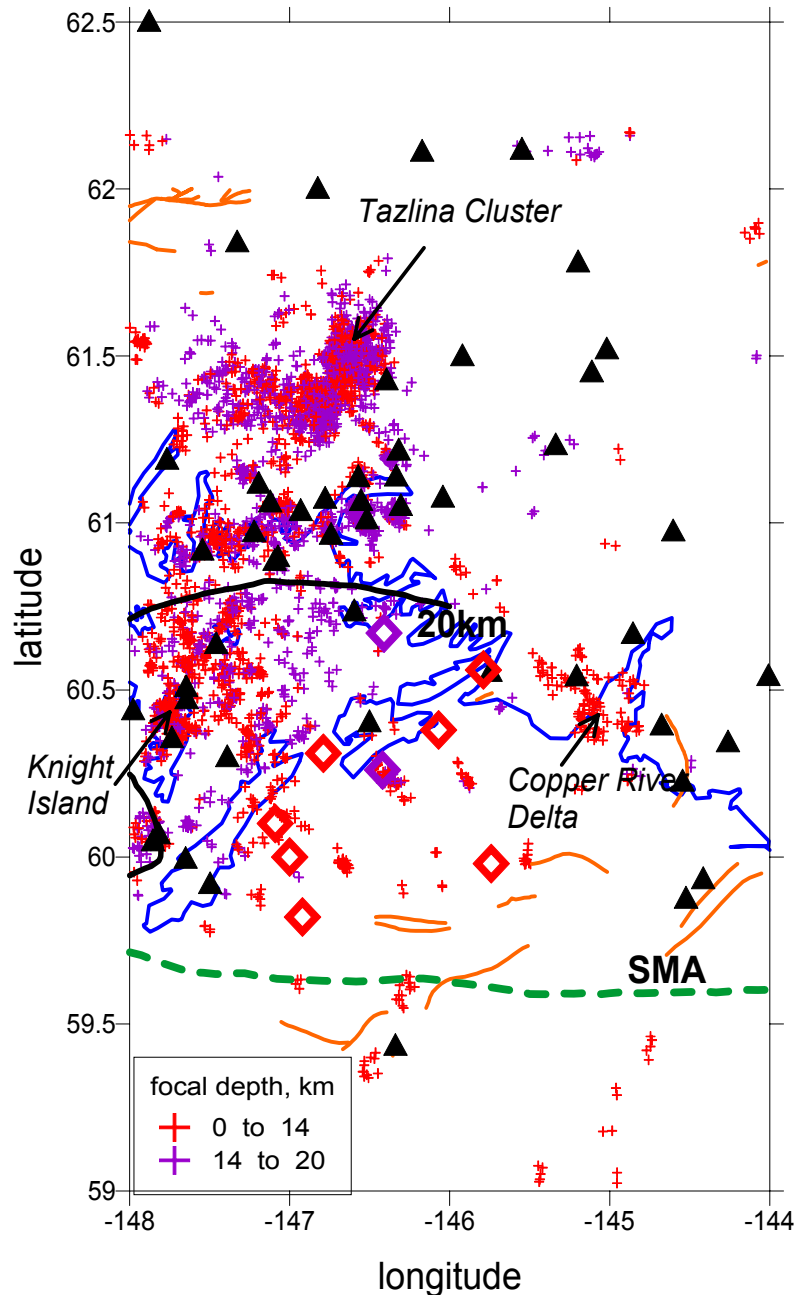


Figure 2 – Shallow seismicity of the PWS region. Plusses are relocated events occurring between 1989 and 2002. Diamonds are $M_w > 5.5$ occurring since the 1964 mainshock. Color scale indicates focal depth. SMA is the Slope Magnetic Anomaly (Griscom and Sauer, 1990) that represents the edge of the subducted Yakutat block. Solid black line is the 20 km depth contour to the plate interface from Brocher et al. (1994). Triangles are seismograph stations.

Important clusters of seismicity are indicated. Orange lines are Holocene/Neogene faults from Plafker et al. (1994).

Figure 3 shows seismicity occurring between 20 and 60 km depth. The 20 km depth contour to the plate interface is from Brocher et al. (1994) and the 30 km depth contour is from Doser et al. (1999). Note that events shown in green located between these two contour lines are occurring very close to the plate interface. Much of the seismicity is concentrated in northwestern PWS and within the Tazlina Glacier region. The squares indicate locations of $M_w > 5.5$ earthquakes occurring between 1928 and 1963 from Doser and Brown (2001). These results show that currently active regions of the PWS have been persistent features for over 70 years.

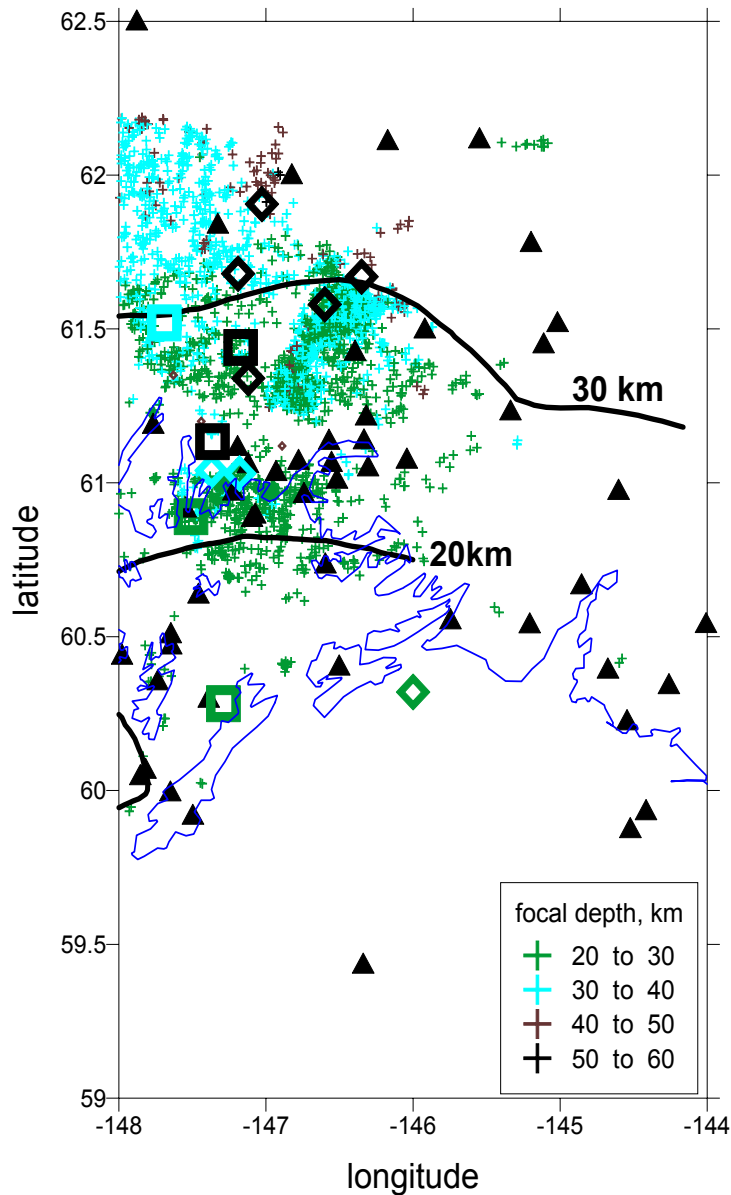


Figure 3 – Relocated events occurring between 1989-2002 at 20 to 60 km depth. Contours represent depth to the plate interface from Brocher et al. (1994) (20 km) and Doser et al. (1999)

(30 km). Diamonds are post-1964 mainshock events with $M_w > 5.5$, boxes are $M_w > 5.7$ earthquakes occurring between 1928 and 1963 studied by Doser and Brown (2001).

Shallow relocated earthquakes (depth < 40 km) of the SKP region are shown in Figure 4. Here all events < 20 km depth (red symbols) are occurring within the North American plate. The 20 km depth to the plate interface is indicated by the contour (Brocher et al., 1994) on the east side of the map, while the 50 km depth to Benioff zone from Plafker et al. (1994) is on the western side of the map. These relocations merge data from the SKP and Anchorage (Flores and Doser, 2005) regions. Note that the seismicity of this region is very diffuse, when compared to the PWS region, but this could be a reflection of the lack of seismograph coverage, especially in the southern portion of the region. Historic (pre-1963) events have occurred in regions that now appear to be seismically quiescent.

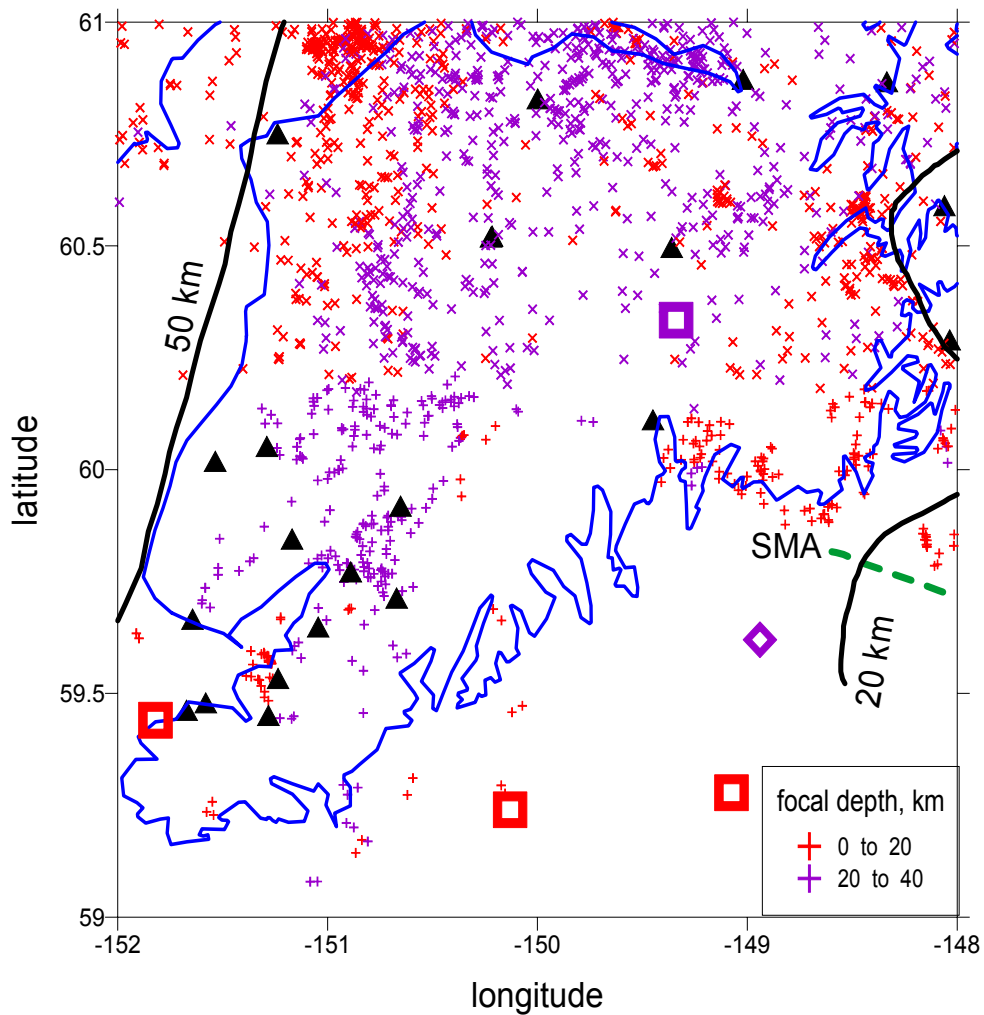


Figure 4 – Seismicity of the SKP/southern Anchorage region. Plusses are events relocated in this study, x's are events relocated by Flores and Doser (2005). Squares are $M_w > 5.7$ earthquakes (pre-1963) from Doser and Brown (2001) and diamonds are post-1964 mainshock $M_w > 5.5$ events. SMA is the Slope Magnetic Anomaly. The 20 km depth to the plate interface is from Brocher et al. (1994) and the 50 km depth to the Benioff zone is from Plafker et al. (1994).

Deeper seismicity (40 to 100 km) of the SKP/southern Anchorage region is shown in Figure 5. All seismicity shown is occurring either in the subducting Yakutat block or the Pacific plate. If we project the Slope Magnetic Anomaly northwest across the Kenai Peninsula it aligns with a zone of intense seismicity located near $\sim 60.25^\circ \text{N}$, 151°W . This zone appears to be an unusual ellipsoidal feature in 3-D (Veilleux and Doser, 2005) and likely represents the deformation of the Pacific plate around the edge of the Yakutat block. Seismicity to the north of this point shows distinctive northeast trending lineations, while seismicity to the south of this point has a more northerly trend. There also seems to be an offset in events at 40 to 60 km depth south of this point, with an accompanying increase in events at depths of 20 to 40 km (Figure 4). Clearly the relationship of this seismicity to the edge of the Yakutat block will be an important feature to investigate.

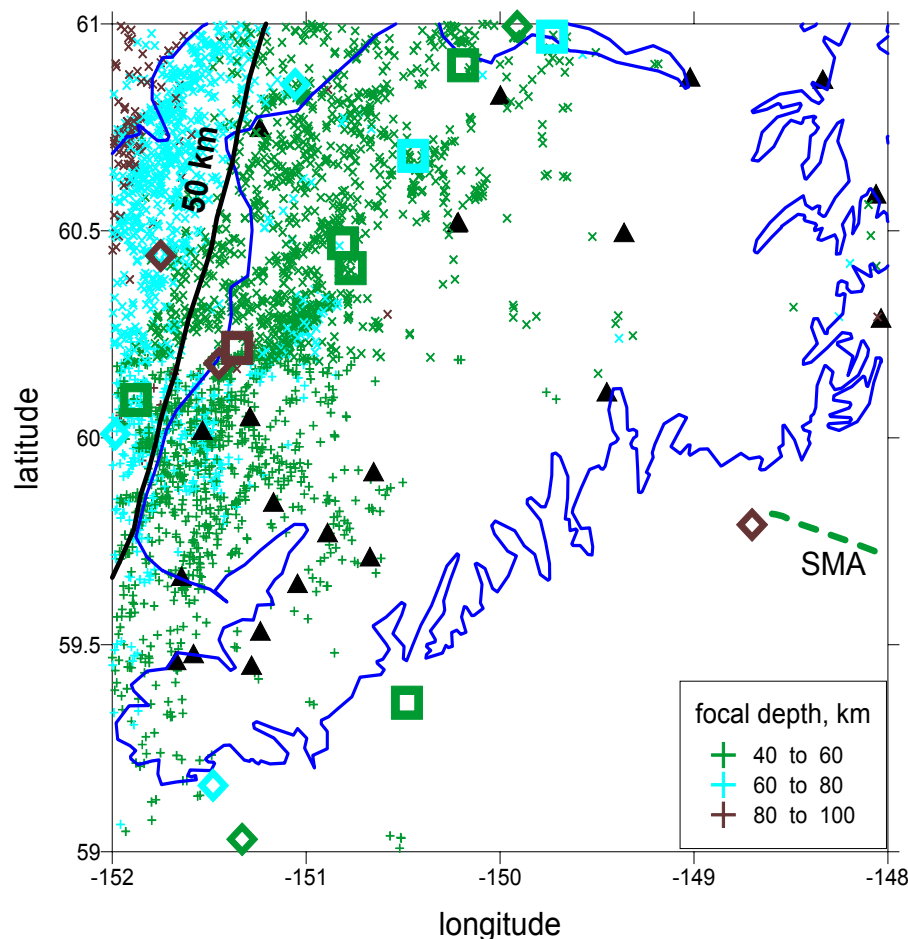


Figure 5 – Deeper (40 to 100 km) seismicity of the SKP/southern Anchorage region. Symbols and labeled features are as in Figure 4.

Task 2 (Examination of the Relation of Seismicity to Lithospheric Structure and Zones of Plate Interface Locking and Relaxation)

Although Page et al. (1989) and Ratchkovsky et al. (1998) have relocated the seismicity of the PWS region; neither study compared the seismicity to the detailed crustal structure models obtained by Brocher et al. (1994). Ye et al. (1997) have also developed a structural model for the southernmost Kenai Peninsula region. Once we complete our relocations and merge data

sets, we will compare our results to these structural models in an effort to understand how the structure of the subduction zone leads to concentrations of earthquakes.

A comparison of our relocations for the PWS and SKP regions to the slip model of Johnson et al. (1996) for the 1964 mainshock is shown in Figures 6 and 7. For the PWS region (Figure 6) seismicity is primarily concentrated in regions where slip was > 5 m during the 1964 mainshock. Study of GPS/geodesy data by Zweck et al. (2002) shows the entire plate interface of the PWS region west of 145 W is currently locked (dashed ellipse, Figure 6), which may explain the abrupt decrease in seismicity observed between 146W and 145W.

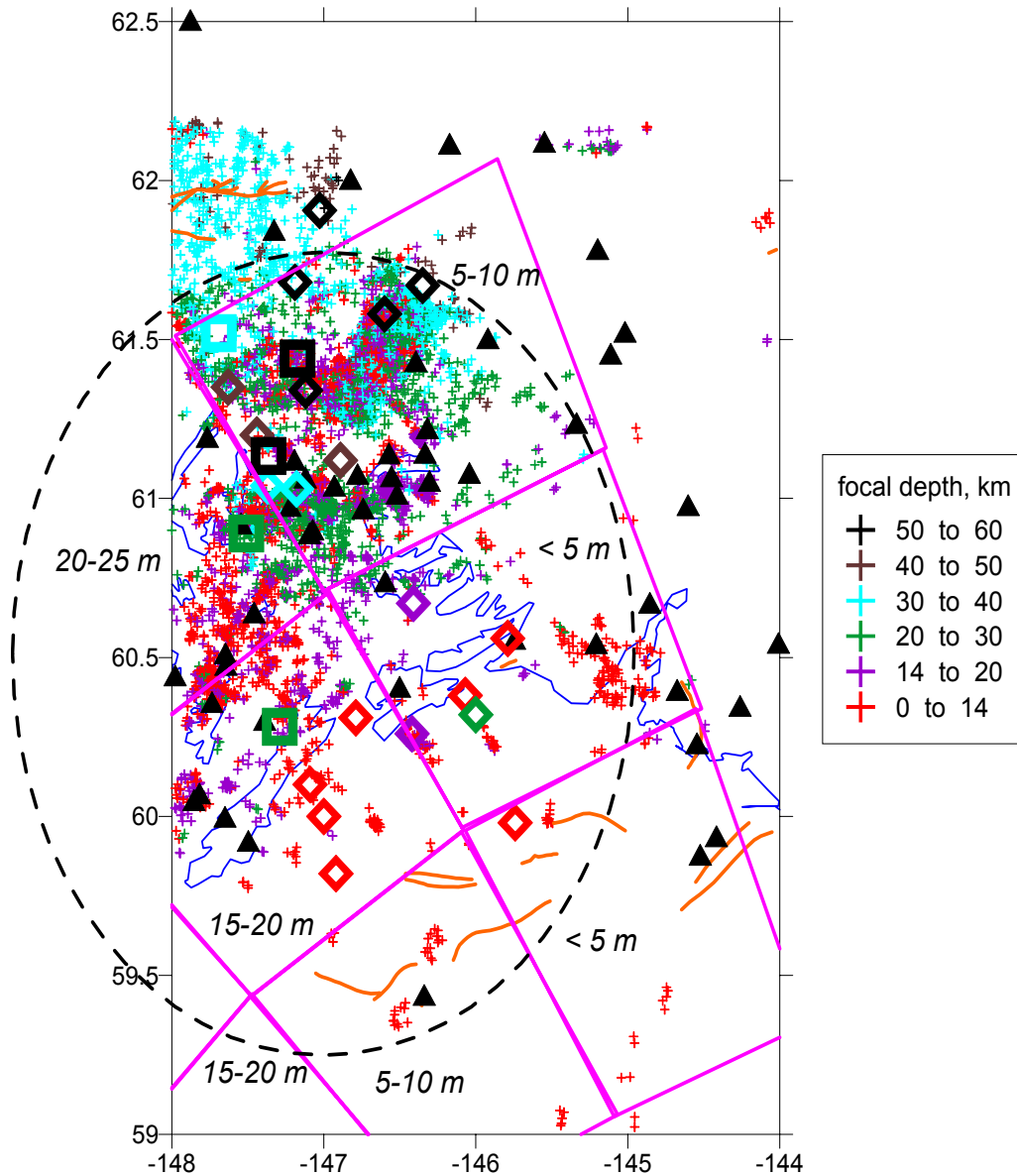


Figure 6 – Relocated seismicity of the PWS region (all depths) compared to slip model of Johnson et al. (1996) for the 1964 mainshock (magenta lines). Italic numbers indicate slip in meters. Dashed ellipse indicates where the plate interface is locked, as determined by Zweck et

al. (2002) from GPS/geodesy studies. Note correspondence of edge of the locked zone to the eastern edge of seismicity and the northern edge of the Tazlina cluster.

Figure 7 compares seismicity of the southern Kenai Peninsula region with the fault displacement model of Johnson et al. (1996) for the 1964 mainshock and the GPS/geodesy studies of Zweck et al. (2002). In the eastern portion of the region the plate interface is locked, while in the western portion of the region the plate interface is slipping aseismically. There is a marked lack of seismicity in the area between the locked and creeping portions of the plate interface, while seismicity in the lower plate increases dramatically downdip of the 1964 rupture zone at the edge of the presently creeping portion of the plate interface.

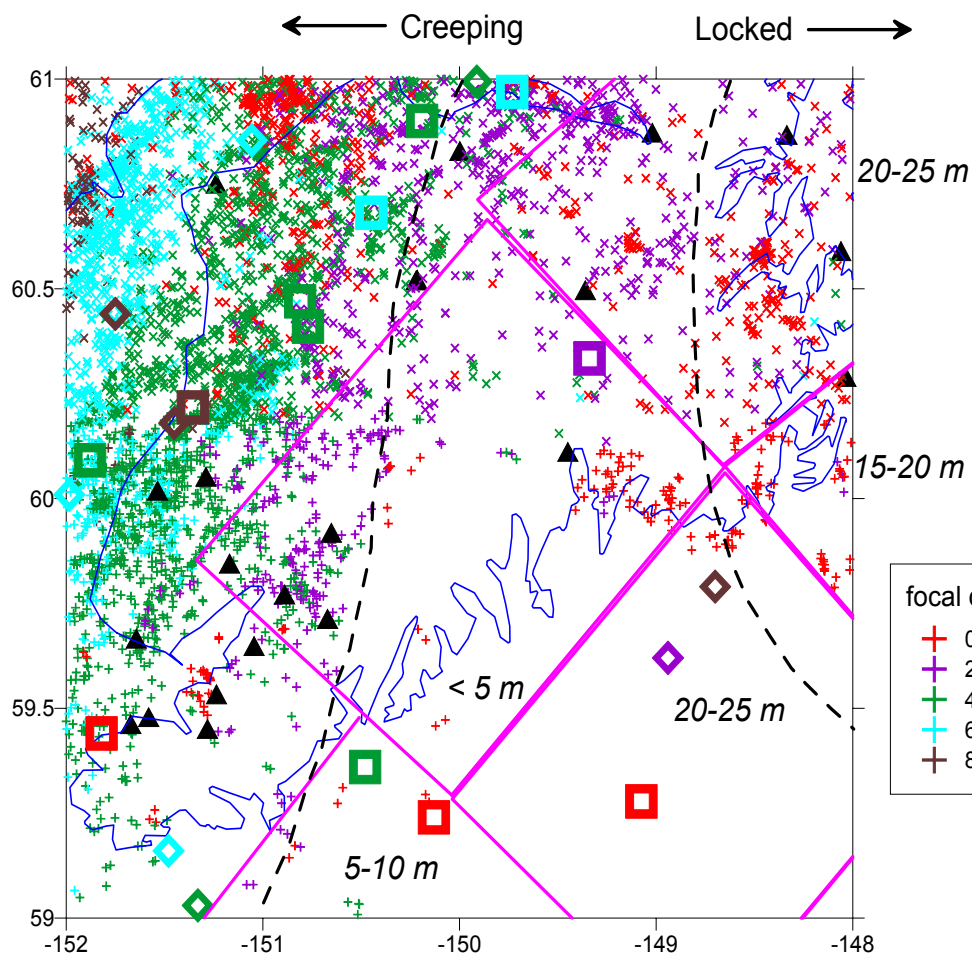


Figure 7 – Relocated seismicity (all depths) compared to the model of slip along the plate interface in the 1964 mainshock (magenta lines, Johnson et al., 1996) with slip in meters noted by italic numbers. Dashed black lines indicate the edges of the creeping and locked portions of the plate interface from Zweck et al. (2002).

Task 3 (Integration with Previous Results)

As Figures 4, 5 and 7 indicate we have already begun to integrate results for the SKP region with the Anchorage region. We will do the same for the PWS and Anchorage regions, as well as relocating events within western Cook Inlet (Figure 1) and merging them with the

relocated seismicity of the other regions. Our integration will produce a detailed picture of deformation within the North American and Pacific plates, and the Yakutat block.

Related Studies

In addition to progress toward our four tasks outlined above, we are in the process of completing analysis of seismicity within the Anchorage region. A paper on the shallow seismicity of this region was published in Flores and Doser (2005) and we plan to submit a paper on Benioff zone seismicity for publication by March 2006. Ms. Veilleux is also completing a waveform modeling study of recent $M \sim 5$ earthquakes occurring within the Benioff zone beneath Anchorage.

Previously funded research on $M > 5.5$ earthquakes of the 1964 great Alaska earthquake rupture zone has led to a paper comparing seismic moment release prior to and after the 1964 mainshock in the PWS and Kodiak asperity regions (Doser et al., 2005). Our results suggest that seismic moment release in the Kodiak region is much more constant through time. However, there have been dramatic decreases in seismic moment release in the PWS asperity region both for events within the North American crust (over a factor of 10 decrease) and the subducting plate(s) (factor of 6 decrease). Results of a previously funded study of pre-1964 events of the Kodiak Island region were also published in Doser (2005a).

We are also completing investigations of the variation in intensity with distance for the south-central, interior and southeastern regions of Alaska that will be submitted for publication by summer 2006. Another outgrowth of this and previous studies was the relocation of south-central Alaska $M > 6.5$ earthquakes occurring between 1899 and 1917 that has been submitted for publication (Doser, 2005b).

Non-technical Summary:

This study focuses on earthquake hazards of the southern Kenai Peninsula and Prince William Sound regions. These regions contain crucial shipping and transportation facilities that serve much of inland Alaska, as well as the terminus for the trans-Alaska oil pipeline. Major tasks in the study are to relocate and merge hypocentral data for the 1964-2002 time period in order to better understand seismic sources within the continental crust (North American plate) and subducting lower plate (Pacific plate and Yakutat block) of these regions. We will also merge our results with previous studies of the Anchorage region to provide a more comprehensive picture of regional seismic hazard and deformation.

Reports Published:

Doser, D.I., Relocation of earthquakes (1899-1917) in south-central Alaska, submitted to Pure and Appl. Geophys., 2005b.

Doser, D.I., Historical seismicity (1918-1964) of the Kodiak Island region, Bull. Seism. Soc. Amer. 95, 878-895, 2005a.

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Availability of Data Sets:

Copies of phase data that are being used in the analysis will be available in digital form. Waveform data are available in digital and/or analog form. Contact the principal investigator, Dr. Diane Dosier, for more details at (915)-747-5851 or doser@geo.utep.edu.